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FINAL REPORT

EARTH CURRENTS FROM UNDERGROUND NUCLEAR DETONATIONS

SGC 43R-18
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ABSTRACT

Experimental facilities were established for the GNOME and HARDHAT tests to measure and record the components of the electromagnetic field generated by underground nuclear detonations. In addition an instrumentation system was established at the GNOME site to investigate the characteristics of the plasma generated by the blast to obtain information concerning the nature and source of the electromagnetic field. Data obtained from the tests shows that the electromagnetic signals generated by low-yield close-coupled underground nuclear explosions are small in magnitude and cannot be detected above background noise at distances greater than a few kilometers from ground zero. Final conclusions concerning the feasibility of electromagnetic detection of decoupled underground nuclear detonations can be made only after the electromagnetic signals from such explosions have actually been measured.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

1.0 INTRODUCTION

In December 1961 and February 1962 Space-General Corporation participated in the GNOME and HARDHAT tests to investigate the feasibility of detecting electromagnetic signals generated by underground nuclear detonations. An experimental facility was established for each event, consisting of vertical, radial, and transverse antennas together with two trailers housing appropriate instrumentation to record and measure the components of the electromagnetic field at two stations approximately six and thirteen miles from ground zero. In addition, for the GNOME test, remote instrumentation was established at a close-in site located 1180 feet from ground zero. Two instrumentation systems were installed at this site, the first to measure and record the three components of the electromagnetic field at close range, and the second to investigate the characteristics of the plasma generated by the blast and to thus obtain information concerning the nature of the source of the electromagnetic field.

Both the GNOME and HARDHAT tests were close-coupled shots in the small yield range. The results obtained from these two tests cannot be extrapolated to the case of de-coupled shots where the detonation occurs in a large underground cavity, for reasons discussed in Section 2.0. The electromagnetic field from a de-coupled shot is expected to be much greater in magnitude than the field from a close-coupled shot; hence the detection of large fields from GNOME and HARDHAT would indicate great promise for the electromagnetic method of detecting "muffled" underground nuclear detonations. The absence of large signals from close-coupled tests, however, does not negate the possibility of detecting de-coupled shots by electromagnetic methods.

The following sections of this report include a theoretical discussion of the generation of electromagnetic pulses by nuclear explosions, a description of the experimental facilities established at both the New Mexico and Nevada test sites, the data obtained during each test, and an evaluation of the feasibility of detecting electromagnetic signals generated by underground nuclear detonations.

2.0 THEORETICAL DISCUSSION

There are two principal mechanisms which have been proposed to explain the generation of an electromagnetic pulse by a nuclear explosion. The first mechanism is the motion, or flow, of Compton electrons which are produced by the interaction of the γ rays released by the nuclear reaction with matter in the vicinity of the burst. While this mechanism is very important whenever there is a large amount of air in the immediate neighborhood of the detonation point (such as in the case of an air shot or an underground "decoupled" shot) it is not expected to be significant in a close-coupled underground burst, such as the GNOME and HARDHAT shots, because of the short mean free path of γ rays in earth. The second mechanism for producing an electromagnetic pulse by a nuclear explosion is the interaction of the earth's magnetic field with the highly conducting, expanding plasma produced by the bomb. Even in close-coupled shots this mechanism will produce an electromagnetic pulse of sufficient magnitude to be detectable at the earth's surface at least at short distances from the burst.

In addition to the magnetic interaction mechanism, a subsurface burst may induce potential differences across antennas lying parallel to the ground by other means. For example, the seismic wave generated by an underground explosion will produce local EMF's as it propagates through the earth. However, a mechanism of this type is clearly distinguished from one which leads to direct radiation by noting the time of onset of the signal since an electromagnetic wave propagates with a much higher velocity than other kinds of waves.

In the following discussion only the direct radiation will be considered.

When a subsurface nuclear explosion occurs, almost all of the energy which is released is absorbed by the surrounding earth. The earth in the immediate vicinity of the burst is vaporized and its constituent atoms are highly ionized. At the same time, a high pressure region is created which causes the ionized material to expand at a high velocity, creating a cavity. The thermal ionization also causes the vaporized material to become a very good conductor. It is well known that matter with a conductivity σ and a velocity $\bar{v}$ will interact with a magnetic field $\bar{B}_o$ (the earth's field) to produce a current density

$$\bar{J} = \sigma\bar{v} \times \bar{B}_o .$$

Thus, a time-dependent current density is created by the interaction of the expanding plasma with the earth's magnetic field and an electromagnetic pulse will be radiated.

The electromagnetic field must satisfy Maxwell's equations, which, in MKS units, are

$$\begin{aligned} \nabla \cdot \bar{E} &= \rho/\epsilon_o \\ \nabla \cdot \bar{B} &= 0 \\ \nabla \times \bar{E} &= -\frac{\partial \bar{B}}{\partial t} \\ \nabla \times B &= \mu \left[\epsilon \frac{\partial \bar{E}}{\partial t} + \sigma_o \bar{E} + \sigma(\bar{E} + \bar{v} \times \bar{B})\right] + \mu\sigma\bar{v} \times \bar{B}_o \end{aligned} \qquad (1)$$

where $\bar{B}$ is the magnetic field generated by the explosion. The total magnetic field is $\bar{B} + \bar{B}_o$. In these equations, σ_o is the conductivity (exclusive of the effects produced by the explosion) of the medium at the point under consideration. Thus σ_o will be zero in air and have a non-vanishing value in the earth.

In addition to the differential equation, boundary and initial conditions must be specified. The tangential components of $\bar{E}$ and $\bar{B}$ must be continuous across the earth-air boundary at the earth's surface as well as at surfaces representing electrical discontinuities in the structure of the earth. Before the explosion occurs, $\bar{E}$ and $\bar{B}$ are zero. Therefore, the initial conditions are $\bar{E} = \bar{B} = 0$ at $t = 0$.

Since σ and $\bar{v}$ are complicated functions of position and time, the solution of the system of Equations (1) presents a formidable problem. However, if the electrical parameters of the earth are functions only of depth below the surface (such as in the case of the GNOME shot, where the earth consisted of homogeneous, horizontally stratified media), then the problem can be considerably simplified by the use of symmetry arguments. Although a complete solution will not be obtained by these arguments, certain predictions can be made concerning the nature of the electromagnetic field at the earth's surface.

Before proceeding with the group theoretical arguments, a few preliminary observations are needed. First, the conductivity σ is a function only of time and radial distance from the detonation point if the burst does not occur at the boundary of two media with dissimilar mechanical properties. This statement is true irrespective of any asymmetry in the construction of the bomb, the reason being that the opacity of the plasma during the initial stages of the expansion is small enough so that any initial temperature (and hence conductivity) asymmetry will decay in a few microseconds. Once the spherical symmetry of the plasma is established, it will remain symmetric because it is expanding against a medium with uniform mechanical properties. This argument also implies that $\bar{v}$, the expansion velocity of the plasma, is a vector directed along the radial direction with respect to the burst origin.

Now, the earth's field will be inclined at some angle Ω to the vertical. If a coordinate system is introduced with the x-axis oriented so that $\overline{B}_o$ is in the x-z plane (see Figure 1) then

$$\overline{B}_o = |\overline{B}_o| \; (-\cos \Omega \, \hat{z} + \sin \Omega \, \hat{x})$$

$$= |\overline{B}_o| \; (-\cos \Omega \, \hat{z} + \sin \Omega \cos \phi \, \hat{\rho} - \sin \Omega \sin \phi \, \hat{\phi}).$$

where $\wedge$ indicates a unit vector in the respective coordinate direction. Here we have introduced cylindrical coordinates (ρ, ϕ, z) in the second line of the equation. From the previous paragraph, we know that $\overline{v}$ has only z and ρ components which do not depend on the angle ϕ. Thus, the driving term $\sigma\overline{v} \times \overline{B}_o$ in the system of Equations (1) will contain terms independent of ϕ and terms proportional to $\cos \phi$ and $\sin \phi$. This means that $\sigma\overline{v} \times \overline{B}_o$ transforms according to the direct sum of the identity representation and the irreducible representation* $\begin{pmatrix} \cos \phi & \sin \phi \\ -\sin \phi & \cos \phi \end{pmatrix}$ of the groups of rotations about the z-axis. Since σ_o is not a function of ϕ and the geometry of the problem remains unchanged by these rotations, the entire problem is invariant under this group. Hence, so is the solution. Thus, the entire ϕ-dependence of $\overline{E}$ and $\overline{B}$ (expressed in the cylindrical basis) will consist of a linear combination of the functions 1, $\sin \phi$, $\cos \phi$. Furthermore, the driving term $\sigma\overline{v} \times \overline{B}_o$ is invariant under reflections in the x-z plane followed by multiplication by -1. Since $\overline{E}$ transforms as a vector and $\overline{B}$ as a pseudovector, this means that E_z, E_ρ, and B_ϕ must be odd functions of ϕ while E_ϕ, B_z, and B_ρ must be

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* that is, irreducible in the field of real numbers.

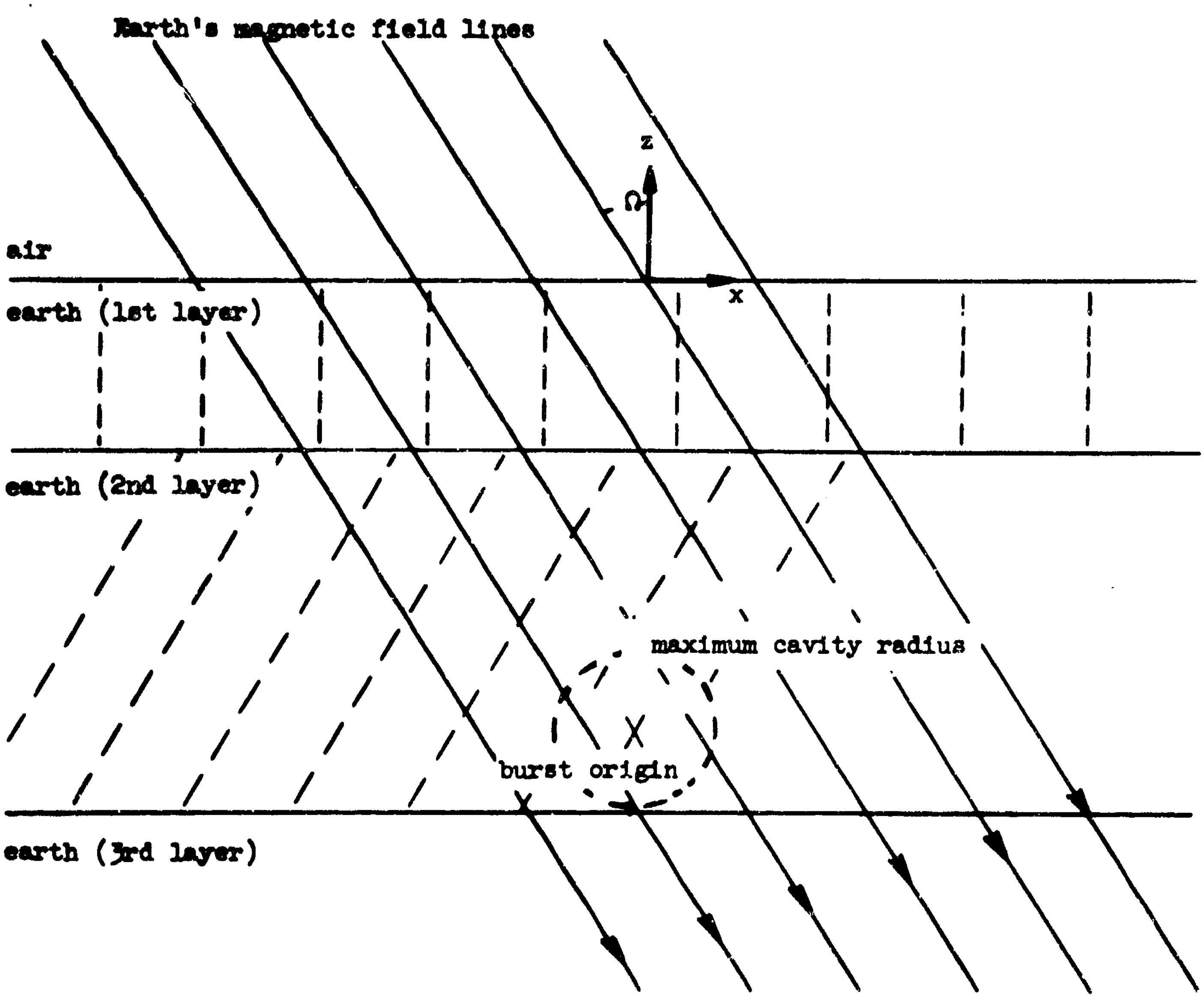

FIGURE 1. Geometry of an Underground Nuclear Explosion

even functions of ϕ. Collecting these results, we find that $\overline{E}$ and $\overline{B}$ should be of the form

$$E_z(\rho, \phi, z) = \sin \phi \, E_z^{(1)}(\rho, z)$$

$$E_\rho(\rho, \phi, z) = \sin \phi \, E_\rho^{(1)}(\rho, z)$$

$$E_\phi(\rho, \phi, z) = E_\phi^{(o)}(\rho, z) + \cos \phi \, E_\phi^{(1)}(\rho, z)$$

$$B_z(\rho, \phi, z) = B_z^{(o)}(\rho, z) + \cos \phi \, B_z^{(1)}(\rho, z)$$

$$B_\rho(\rho, \phi, z) = B_\rho^{(o)}(\rho, z) + \cos \phi \, B_\rho^{(1)}(\rho, z)$$

$$B_\phi(\rho, \phi, z) = \sin \phi \, B_\phi^{(1)}(\rho, z)$$

The time-dependence of the fields has not been indicated explicitly in these equations.

It is seen that the field components have a simple dependence on angular position from a north-south line through ground zero with E_z, E_ρ, and B_ϕ vanishing at points directly north or south of the explosion and E_ϕ, B_z, and B_ρ having maximum values along a north-south line.

The problem of the electromagnetic pulse which is generated by the interaction of the earth's magnetic field with the highly conducting plasma from a nuclear explosion has been solved by Space-General for the case of an underground de-coupled explosion.[1] Although the results from this solution cannot be applied directly to close-coupled shots such as GNOME and HARDHAT, the field strengths obtained perhaps represent upper bounds on the

(1) SGC 68R-7 "Theoretical and Model Studies for the Production and Propagation of Electromagnetic Signals from Underground Nuclear Explosions", Volume I, Theoretical Studies, AF30(602)-2500.

field values from close-coupled shots since the plasma expands more rapidly and into a larger volume when the shot takes place in a large cavity. The referenced report is classified confidential, but we can get a "horseback" estimate of the field strength to be expected from a close-coupled shot by following Wouters order-of-magnitude analysis of the problem.(2)

Wouters considers that the plasma generated by the bomb is a good conductor and that the hydrodynamic explosion pushes away the earth's magnetic lines of force, so that in effect, a local magnetic field distribution is created which opposes the initial distribution of the earth's magnetic field. This new distribution can be expressed as a set of multipoles, the most important of which is assumed to be the magnetic dipole term. As a first approach to the problem it is assumed that the magnetic dipole field opposes and balances the earth's field at the edge of the final cavity radius which is of the order of 20 feet. This requires a magnetic dipole moment of approximately 2×10^5 ampere-square meters. Since frequencies much above 1 kc will be greatly attenuated in propagating through the earth, we can solve for the electric field which will be produced if the time variation of the magnetic dipole is such that most of the electromagnetic energy is concentrated around the 1 kc region.

The free space electric field from an oscillating magnetic dipole, in the direction of maximum electric field and in the

(2) L. F. Wouters, "Magnetic Field Effects from Underground Nuclear Detonations - Some Preliminary Thoughts" UOPB 60-20 Rev. 1, 28 January, 1960, Lawrence Radiation Laboratory, Livermore, California.

induction region at distances less than a wavelength, is[3]

$$|E| = \frac{1}{2\lambda} \sqrt{\frac{\mu}{\epsilon}} \left(\frac{1}{R^2}\right) P$$

where λ is the electromagnetic wave-length, $\frac{\mu}{\epsilon} = 376.7$ ohms for free space, R is the radial distance from the dipole and P is the magnetic dipole moment. Neglecting the attenuation in the earth and the effect of the earth-air interface, the electric field strength at a distance of 500 meters from the explosion should be of the order of 1 mv/meter. At a distance of 5 km the field strength will have decreased to 10 μv/meter. While this analysis is crude, the indications are that if the magnetic field interaction is indeed the principal source of the electromagnetic field from a close-coupled shot, then the electric field at the earth's surface will be small and will be undetectable from the background noise at distances of more than a few kilometers from ground zero. Actual measurements of field strengths must be made, of course, before the tentative conclusions based on these tenuous arguments can be made definite.

(3) Stratton, J. A., "Electromagnetic Theory", McGraw-Hill, page 437.

3.0 EXPERIMENTAL FACILITY - GNOME TESTS

3.1 AREA DESCRIPTION

The GNOME site was located about 40 km southeast of Carlsbad in Eddy County, New Mexico. The GNOME shot, which involved the underground detonation of a 3 ± 1 kt nuclear device,[4] was conducted at a point 303 meters on a bearing N 49° 43'11" E from the center of Section 34, Township 23 South, Range 30 East, New Mexico Principal Meridian, at a depth from the surface of approximately 365 meters. The device was detonated at the end of a 340 - meter hooked tunnel in the Salado formation, a bedded salt formation consisting mainly of halite. In the shot area the top of the Salado formation is about 216 meters below the ground surface. The Salado is overlain by bedded formations of amhydrite, dolomite, claystone, siltstone, and sandstone. A map of the area, showing the location of the three Space-General instrumentation sites, is presented in Figure 2.

3.2 STATION I - CLOSE-IN SITE

Station I instrumentation was installed in the Chemistry-Radiation building 1170 ft from ground zero. The antenna complex was located 165 ft from this building and 1180 ft south 35° 30' west of ground zero. This station was operated remotely and was established to obtain close-in measurements and recordings of 1) the potential and characteristics of the plasma generated by the blast, and 2) the vertical, radial, and transverse components of the electromagnetic field generated by the explosion.

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(4) University of California Radiation Laboratory Memo UOPAC 62-75, Livermore, California, 28 March 1962.

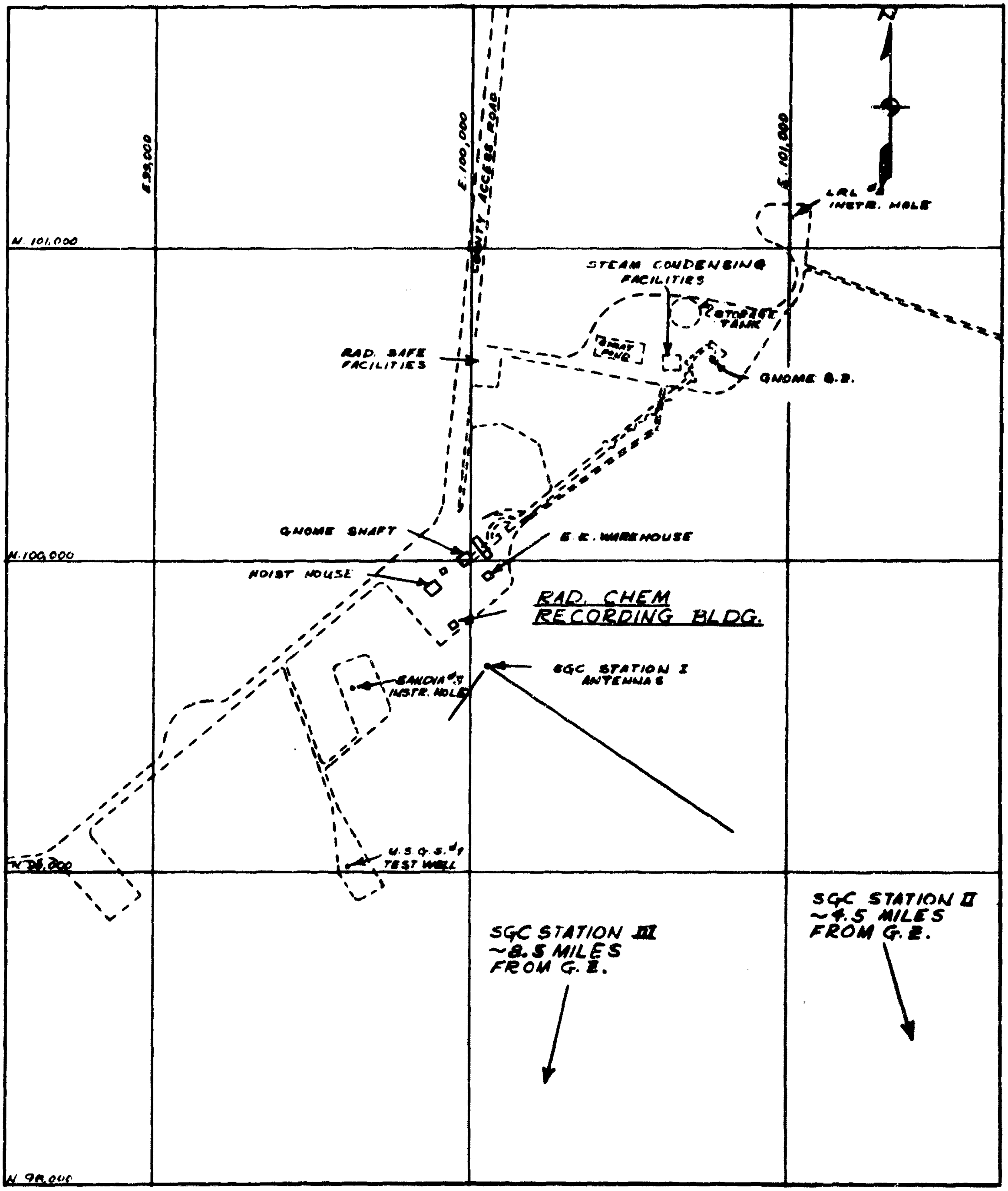


FIGURE 2. Area Map of GNOME Site

3.2.1 Plasma Probe

The purpose of the plasma probe experiment was to make qualitative measurements of the characteristics of the plasma generated by an underground nuclear detonation. The instrumentation system (shown in Figure 3) was designed to measure and record the voltage appearing on the neutron pipe during the course of the explosion in order to provide data concerning the temperature of the plasma and the contribution of the pipe in radiating electromagnetic energy. Unfortunately, however, escaping radioactive steam caused fogging of the film in the oscilloscope cameras and precluded the successful recording of data.

3.2.1.1 Test Procedure

The equipment used in this portion of the experiment consisted of the following:

- 2 Tektronix 545 oscilloscopes
- 1 Tektronix 515 oscilloscope
- 3 Beattie - Coleman/Lord oscilloscope cameras
- 1 Fabricated 1000 - ohm resistance network consisting of 10 sets of 10 parallel 1 K resistors connected in series (see Figure 4).

The Tektronix model 545 oscilloscopes were desirable for this experiment because they were equipped with a single sweep control which allowed only one sweep at the time of detonation. However, since only two of these units were available, it was necessary to use a model 515 oscilloscope, which, nevertheless, was adequate. Also the Beattie - Coleman cameras were chosen because they were equipped with solenoid-operated shutters which could easily be operated by the timing relays

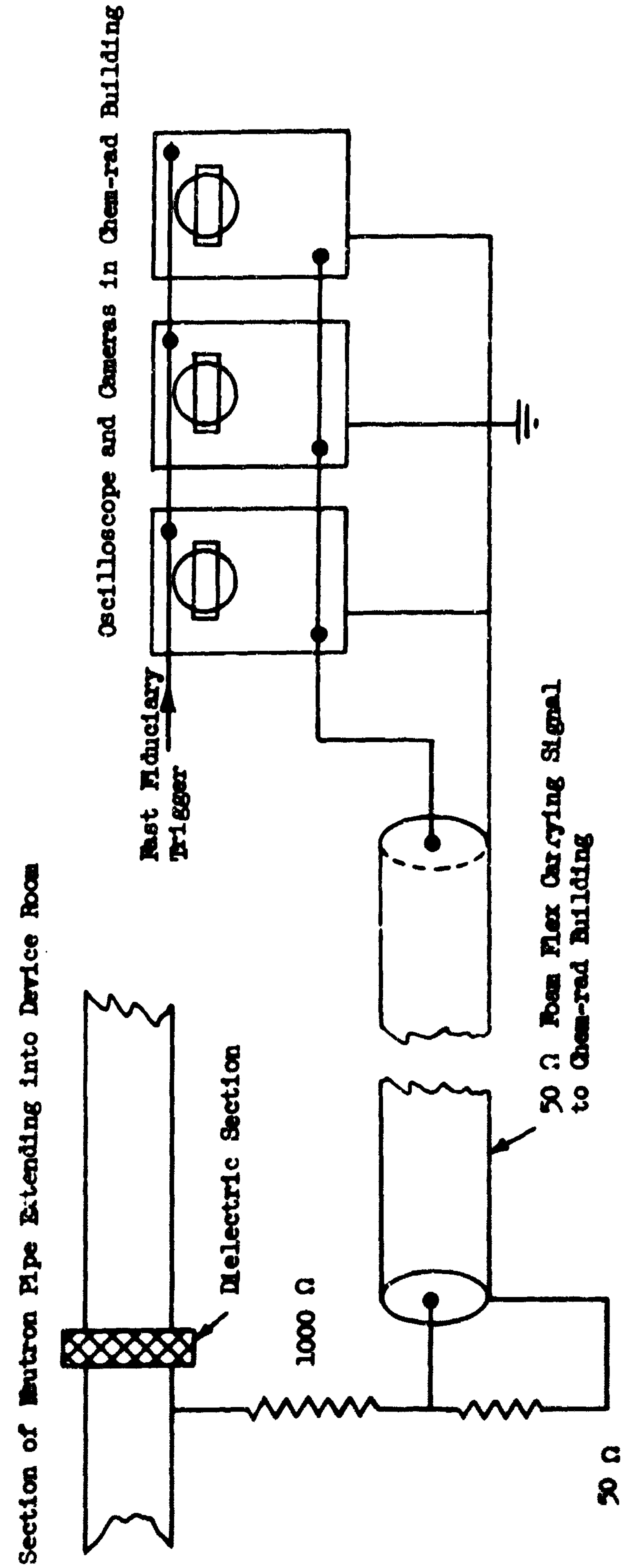


FIGURE 3. Instrumentation for Plasma Probe Experiment

supplied by the AEC. In regard to the resistor network, it was decided that a fabricated network consisting of several parallel elements connected in series would provide much greater reliability than a single resistor with the same power rating.

The trigger signal operating the oscilloscope sweeps was a fast fiduciary originating at the start of the blast. The sensitivities and sweep speeds of the oscilloscopes were set as follows:

I	30 volts/cm	-	0.5 μs/cm
II	5 volts/cm	-	10.0 μs/cm
III	2 volts/cm	-	100.0 μs/cm

These sensitivities and sweep speed were chosen to best record all phases of the first millisecond of the blast. It was anticipated that the voltage on the pipe would rise rapidly to perhaps thousands of volts during the first few microseconds and then decay in probably an exponential manner during the following millisecond.

The voltage generated by the plasma was picked up at the end of the first section of vacuum pipe and was passed through the resistance network and then carried to the oscilloscopes by 1 - inch Foam-Flex coaxial cable. This reduced voltage was presented to the oscilloscope signal inputs and recorded by the cameras. The camera shutters were operated by a relay which closed at T-1 second and remained closed until T + 1 second. All data was lost because of complete radioactive fogging of the camera film.

3.2.2 Electromagnetic Field Measurements at Station I

In addition to the plasma probe instrumentation, vertical, radial, and transverse antennas (as shown in Figure 4) were

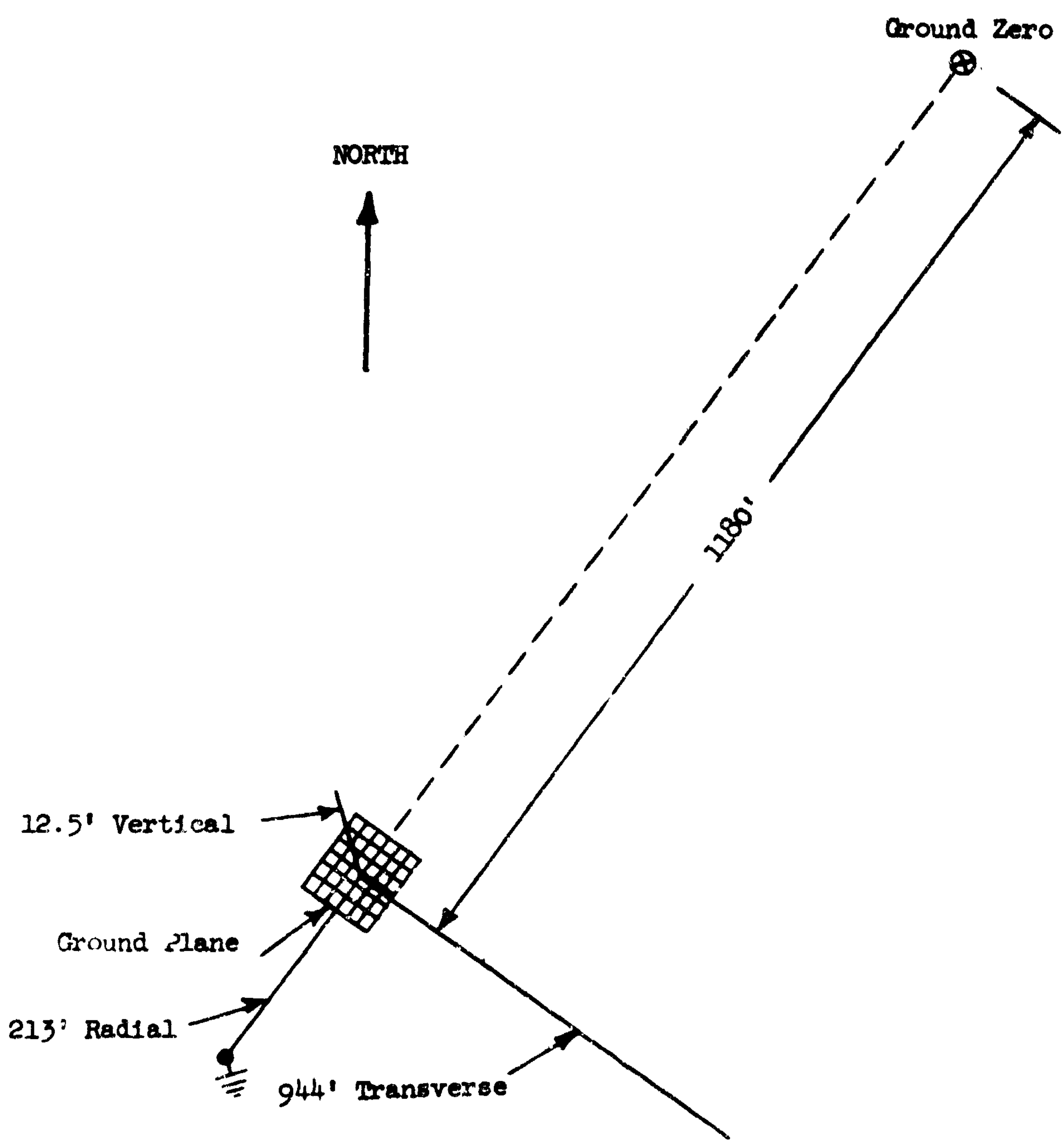


FIGURE 4. Antenna Configuration - STATION I, GNOME

established at Station I to obtain close-in surface measurements of the components of the electromagnetic field generated by the explosion. Instrumentation used in this portion of the experiment consisted of the following:

1 Precision Instrument seven-channel magnetic tape recorder Model PI-207
3 Tektronix RM-122 preamplifiers
1 Filter panel consisting of five sets of filters, each set consisting of one each 60 cps, 180 cps, 300 cps notch reject filters and a 10 kc low pass filter, all in series.
1 400 cps reference oscillator
1 SGC-constructed cathode follower
Batteries to operate the recorder and preamplifiers

A block diagram of the instrumentation system is shown in Figure 5. The Station I radial antenna was 213 ft long, the transverse antenna was 944 ft long, and the vertical antenna was 12.5 ft high. A 12' x 12' square of chicken wire was used as a ground plane for the vertical antenna, and the radial and transverse antennas were each terminated in a pyrex gouch-crucible with a cadmium electrode. A saturated solution of cadmium chloride was used as an electrolyte in the crucible to ensure proper contact with ground.

The magnetic tape recorder was furnished with four channels of FM recording and three direct record channels. The band pass on data channels which were FM recorded was from about 1 cps to 7 kc (3 db points) with about 60 db rejection at 60, 180, and 300 cps. The band pass curve for the radial antenna data channel is shown in Figure 6. This curve is typical of all the data channels with the exception of the vertical antenna data channel which used direct

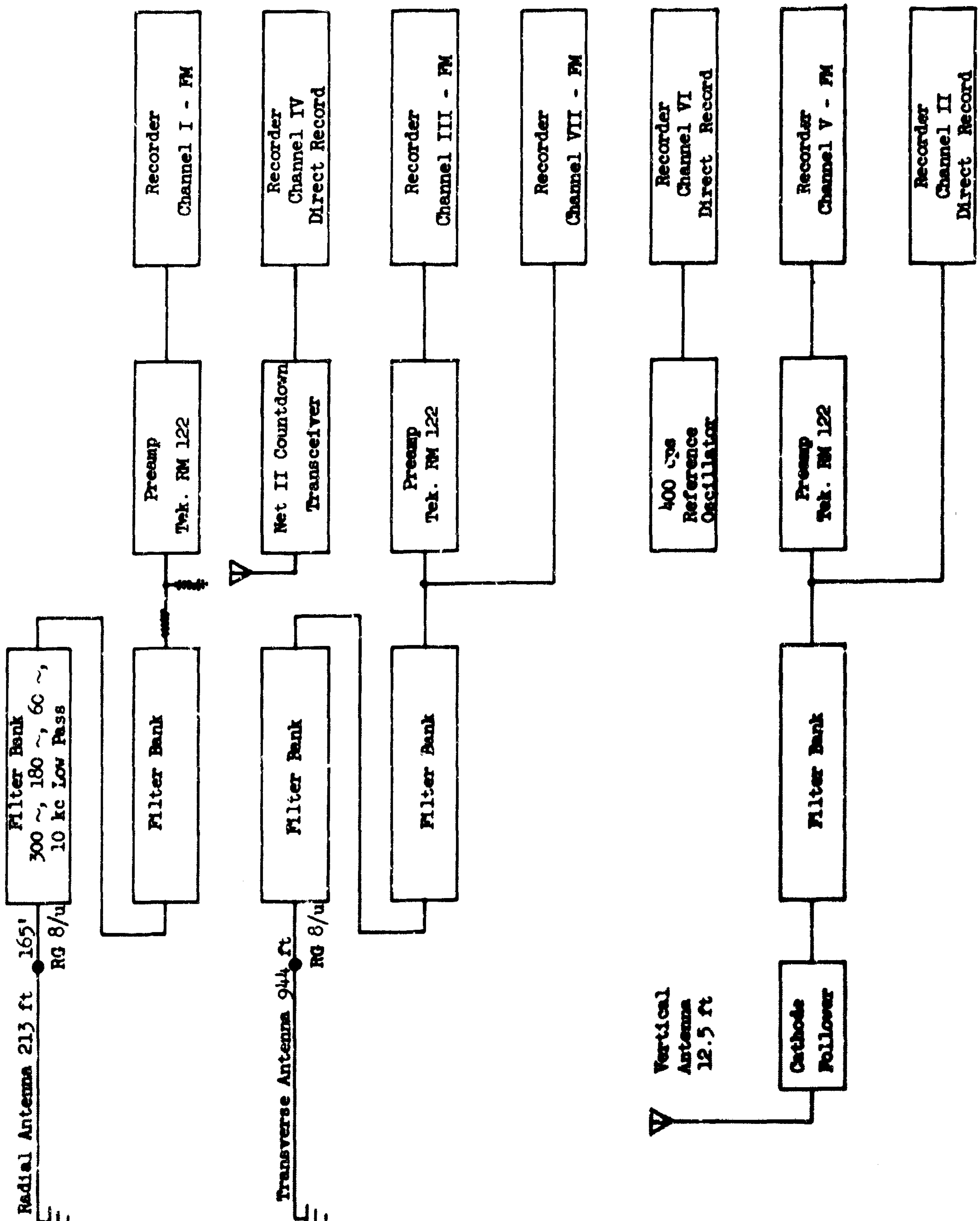


FIGURE 5. Instrumentation System for Recording E.M. Signals Generated by Underground Nuclear Detonation - Station I, GNOME

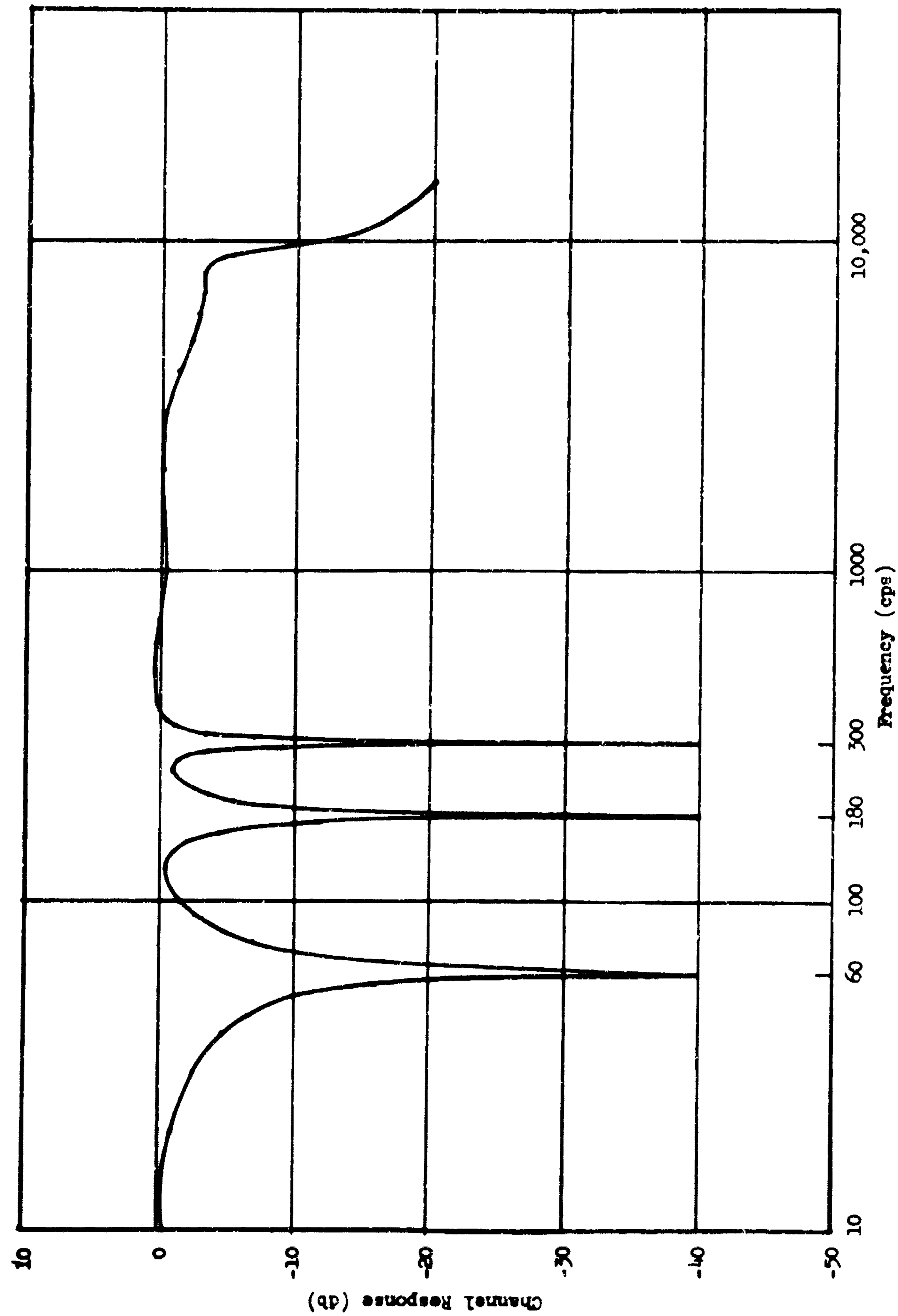


FIGURE 6. Band Pass Curve For Radial Antenna Channel, Station I, GNOME

recording. In this case the band pass was from 20 cps to 7 kc.

The signals from the transverse and vertical antennas were each recorded with and without preamplification. This was done to increase the dynamic range of the data system to 60 db above noise level for these two antennas.

3 2.2.1 Test Procedure

At T-8 hours a calibration recording was made of all signal channels by feeding a 500 cps signal into all antenna inputs, which were connected in parallel. The signal was started at a level of 1 millivolt rms and then increased in 10 db steps to a level of 3.16 volts rms. A channel-by-channel frequency response check was also made at this time starting at 20 cps and ending at 10 kc.

At T-15 minutes the amplifiers were turned on by relays provided by the AEC, and at T-1 minute the tapes were started. Channel assignments were as follows:

CHANNEL I

The radial antenna was connected to two filter sets in series, and the output of the filter bank was attenuated 11:1 by a resistor network between the filter bank and the RM 122 preamplifier input. This setup was necessary because of the high noise level on the antenna. The Channel I dynamic range extended from about 0.01 volt rms (noise level) to 2.0 volts rms (46 db) input from the antenna.

CHANNEL II

The vertical antenna was connected through a cathode follower to a filter bank. Because of the inherently large impedance of the vertical antenna, the cathode follower was necessary to match the impedance of the antenna to the filter bank. Channel II dynamic range was 0.1 volt rms to

2.0 volts rms (26 db). This channel malfunctioned with loss of data.

CHANNEL III

The transverse antenna was connected to two filter banks in series; the output of the filter banks was connected to the input of an RM 122 preamplifier. Channel III dynamic range was 0.003 volt rms to 0.3 volt rms (40 db).

CHANNEL IV

Voice countdown and timing signals from the net 2 radio were recorded on Channel IV.

CHANNEL V

Channel V was similar to Channel II, with the addition that the output of the filter bank was connected to the input of a RM 122 preamplifier to increase the dynamic range of the vertical antenna. Channel V dynamic range was 0.003 volt rms to 0.1 volt rms (32 db).

CHANNEL VI

Channel VI was the input from the 400 cps tuning fork reference oscillator.

CHANNEL VII

Channel VII was similar to Channel III with the exception that the output of the filter bank was connected directly to the recorder input of Channel VII. Channel VII dynamic range was 0.20 volt rms to 3.0 volts rms (24 db).

3.3 STATION II

Station II was located on the Snyder Ranch approximately 4.5 miles south by southeast of ground zero (see Figure 2). The immediate area surrounding this site is typical of the entire area (Southwestern desert), although the conductivity of the soil was considerably greater than expected due to rainfall prior to the test shot. The resistance measured from the horizontal antenna wires to the instrumentation ground was less than 10k ohms at all three stations.

The purpose of Station II was to obtain measurements of the three components of the electromagnetic field strength during the test by establishing antennas and appropriate instrumentation similar to the facility at Station I.

3.3.1 Electromagnetic Field Measurements at Station II

At this station the radial antenna was 590.5 ft long, the transverse antenna was 495.5 ft long, and the vertical antenna was 12.5 ft high. Each horizontal antenna was grounded at its far end by means of a cadmium electrode immersed in a cadmium chloride solution contained in a porous crucible buried in the ground. The instrumentation at this site, which was housed in a 14' x 8' trailer, was operated manually and consisted of the following:

- 1 Precision Instrument 7-channel magnetic tape recorder Model PI-207
- 2 Philbrick P-2 DC amplifiers
- 1 Tektronix RM-122 preamplifier
- 1 400 cps reference oscillator
- 1 Portable transceiver for communication and to record voice countdown and timing signals
- 1 Filter panel consisting of three sets of filters, each set consisting of one each 60 cps, 180 cps, and 300 cps notch filters and a 10 kc low pass filter, all in series.

1 SGC-constructed cathode follower

Batteries to operate the recorder, preamplifiers, and cathode follower.

A 5 kv gasoline engine generator for battery charging and stand-by operation.

With the exception of the two Philbrick DC amplifiers (which were used because additional Tektronix RM-122 preamplifiers were not available) the system (shown in Figure 7) was almost identical to that at Station I.

The frequency bandpass for the signals from the transverse and radial antennas was from DC to about 7 kc with about 50 db rejection at 60, 180, and 300 cps. The band pass for the vertical antenna was from about 20 cps to 7 kc with 50 db rejection at 60, 180, and 300 cps. Band pass curves are similar to that shown in Figure 6. By using two recording channels each for the radial and transverse antennas, the dynamic range was extended to 60 db.

3.3.1.1 Test Procedure

At T-6 hours a calibration recording was made of all signal channels by feeding a 500 cps signal into all antenna inputs, which were connected in parallel. This signal was started at a level of 0.001 volts rms and increased in 10 db steps to 3.16 volts rms using a variable attenuator. A channel-by-channel frequency response check was also made at this time.

At T-1 hour the amplifiers were turned on and at T-15 minutes the recorder was started to record the voice announcement, then stopped. This procedure was repeated at T-5 minutes. The recorder was started for the final run just prior to the T-2 minute announcement and was allowed to run for approximately 20 seconds past T_o seconds. Also,

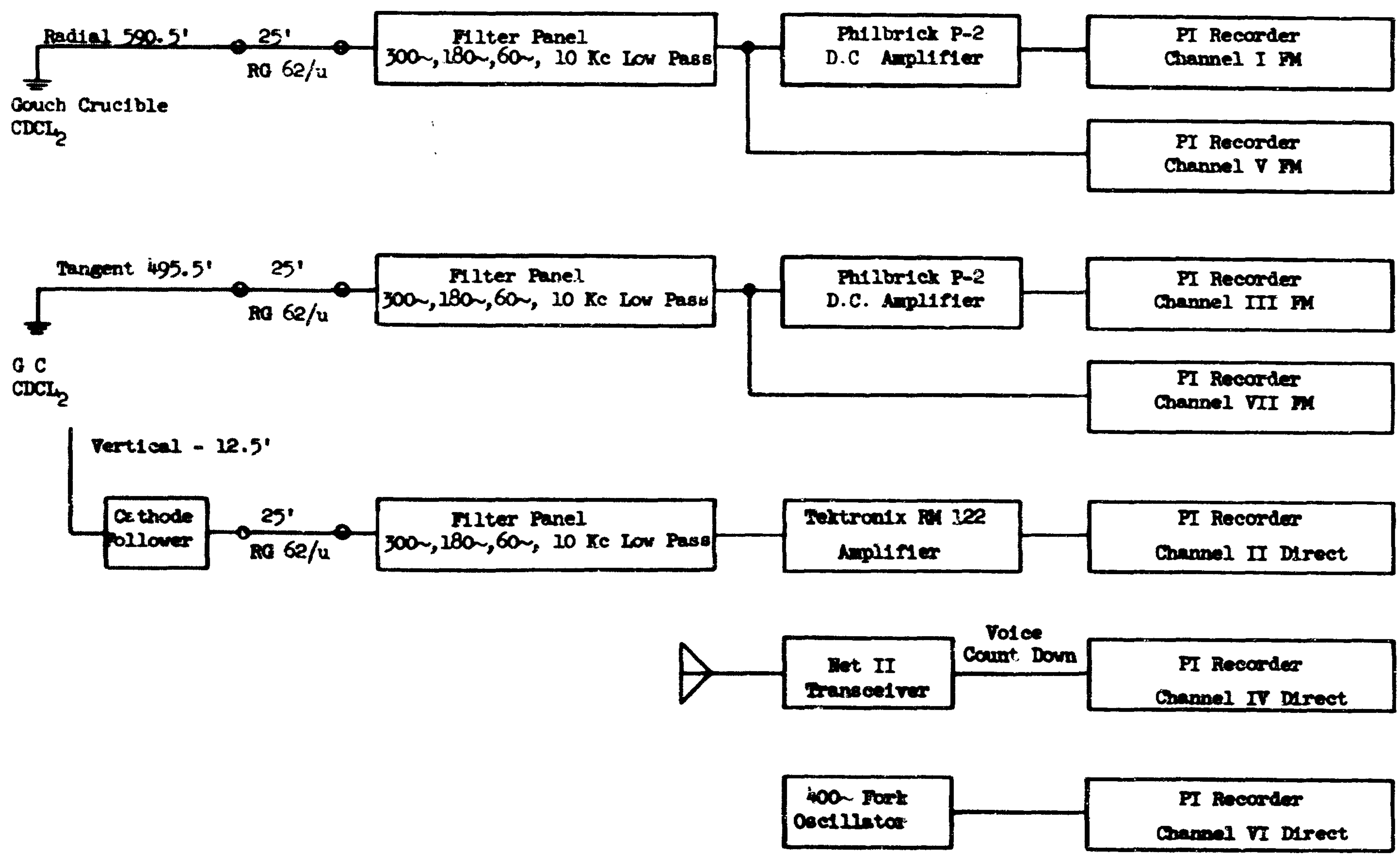


FIGURE 7. Instrumentation System at Station II - GNOME Test

during the last two minutes of countdown the output of Channel I (radial antenna) was visually monitored on a Tektronix 515 oscilloscope. Channel assignments at Station II were as follows:

CHANNEL I

The radial antenna was connected to a filter bank and to the recorder through a Philbrick P-2 DC amplifier. The dynamic range of Channel I was 0.001 v rms to 0.06 v rms input from the antenna.

CHANNEL II

The vertical antenna was connected to the recorder through a cathode follower, filter bank, and RM-122 preamplifier. The dynamic range of this channel was 0.01 v rms to 1.0 v rms.

CHANNEL III

The transverse antenna was connected to the filter bank and to the recorder through a Philbrick P-2 DC amplifier. The dynamic range of Channel III was 0.001 v rms to 0.07 v rms.

CHANNEL IV

Voice countdown and timing signals from the net 2 radio were recorded on Channel IV.

CHANNEL V

On Channel V the radial antenna was connected directly through the filter bank to the recorder input. The dynamic range of this channel was 0.05 v rms to 1.0 v rms.

CHANNEL VI

Channel VI was the input from the 400 cps tuning fork reference oscillator.

CHANNEL VII

On Channel VII the transverse antenna was connected directly through the filter bank to the recorder input. The dynamic range of Channel VII was 0.05 v rms to 1.0 v rms.

3.4 STATION III

Station III was located 8.5 miles south by southwest of ground zero approximately three miles due east of the main housing complex of the Harroun Ranch (see Figure 2).

3.4.1 Electromagnetic Field Measurements at Station III

The radial antenna at Station III was 1750 ft long, the transverse antenna was 1000 ft long, and the vertical antenna was 12.5 ft high. Both horizontal antennas were terminated to ground in pyrex gouch-crucibles with cadmium electrodes, and a 12 - foot square of chicken wire was used as a ground plane for the vertical antenna. The following is a list of equipment used at this station:

3 Roberts 2-channel recorders model 990
1 Filter panel consisting of three sets of filters, each set consisting of one each 60 cps, 180 cps, and 300 cps notch reject filters and a 10 kc low pass filter, all in series
1 SGC cathode follower
1 400 cps reference oscillator
1 Portable transceiver for communication and to record voice countdown and timing signals
Batteries to operate the equipment
A 5 kv gasoline engine generator for battery charging and standby operation.

A block diagram of the instrumentation system is shown in Figure 8.

3.4.1.1 Test Procedure

At T-6 hours the equipment used in the test was calibrated using a signal generator and a variable step attenuator. The generator was set to 500 cps with an output level attenuated to 0.001 v rms. This level was increased in 10 db steps to 3.16 v rms, each step being recorded for a period of one minute. This procedure was followed for each channel of information.

Operating procedures at Station III were identical to those at Station II. Unfortunately, two of the recorders at Station III failed prior to the event and the only channel of data recorded at this station was that of the radial antenna.

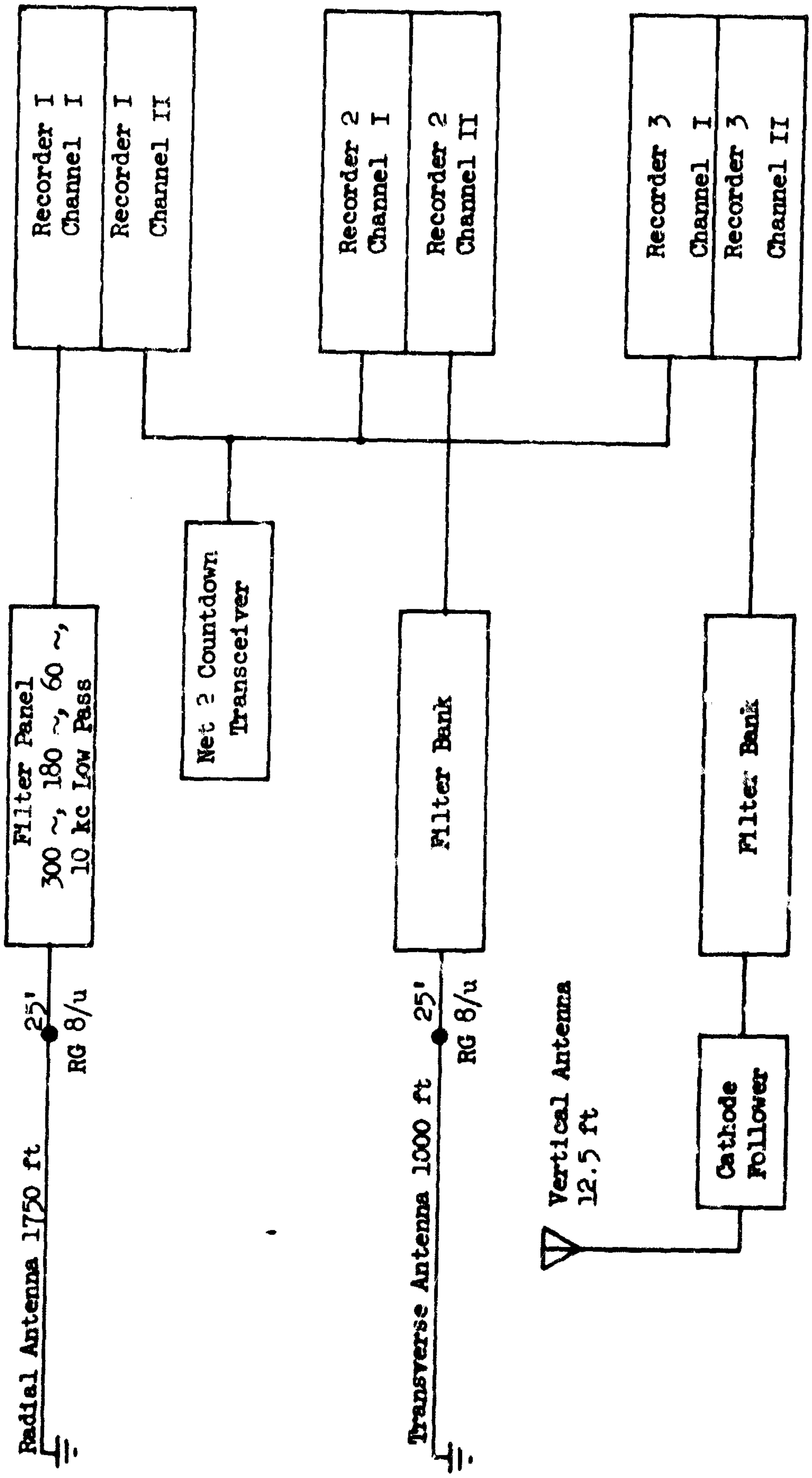


FIGURE 8. Instrumentation System at Station III - GNOME Test

4.0 EXPERIMENTAL FACILITY - HARDHAT TESTS

In general, the test operations conducted for HARDHAT were similar to those for GNOME except that only two stations were instrumented (both manually operated) and all instrumentation was battery-powered. The instrumentation at each station was housed in a 14-ft trailer and consisted of the following:

- 1 Precision Instrument seven-channel tape recorder Model PI-207 and battery-powered motor-drive amplifier.
- 3 Tektronix RM-122 preamplifiers.
- 4 filter sets, each set consisting of one each 60 cps, 180 cps, 300 cps notch rejection filters and a 10 kc lowpass filter, all in series.
- 1 cathode follower.
- 1 400 cps reference oscillator.
- 1 portable transceiver for communication and to record voice countdown and timing signals.
- Batteries to operate the equipment
- 1 gasoline engine generator for battery charging and standby operation.

A block diagram of the instrumentation system, which was identical at both stations, is shown in Figure 9.

Station I was located 65,754 ft south 4° 7' 13" west of ground zero. Tippipah Springs NE map reference is Station 101.01 N 836,374.4 ft, E 671,913.37 ft. The radial antenna length was 2156 ft, transverse antenna 2137 ft, and the vertical antenna 12.5 ft.

The Station II equipment was located 36,738 feet South 19° 01' 06" east of ground zero. Tippipah Springs NE map reference is Station 901.01 N 867,200.46 feet, E 688,796.14 feet. The radial antenna length was 2160 ft, transverse 2320 ft, and the vertical antenna 12.5 ft.

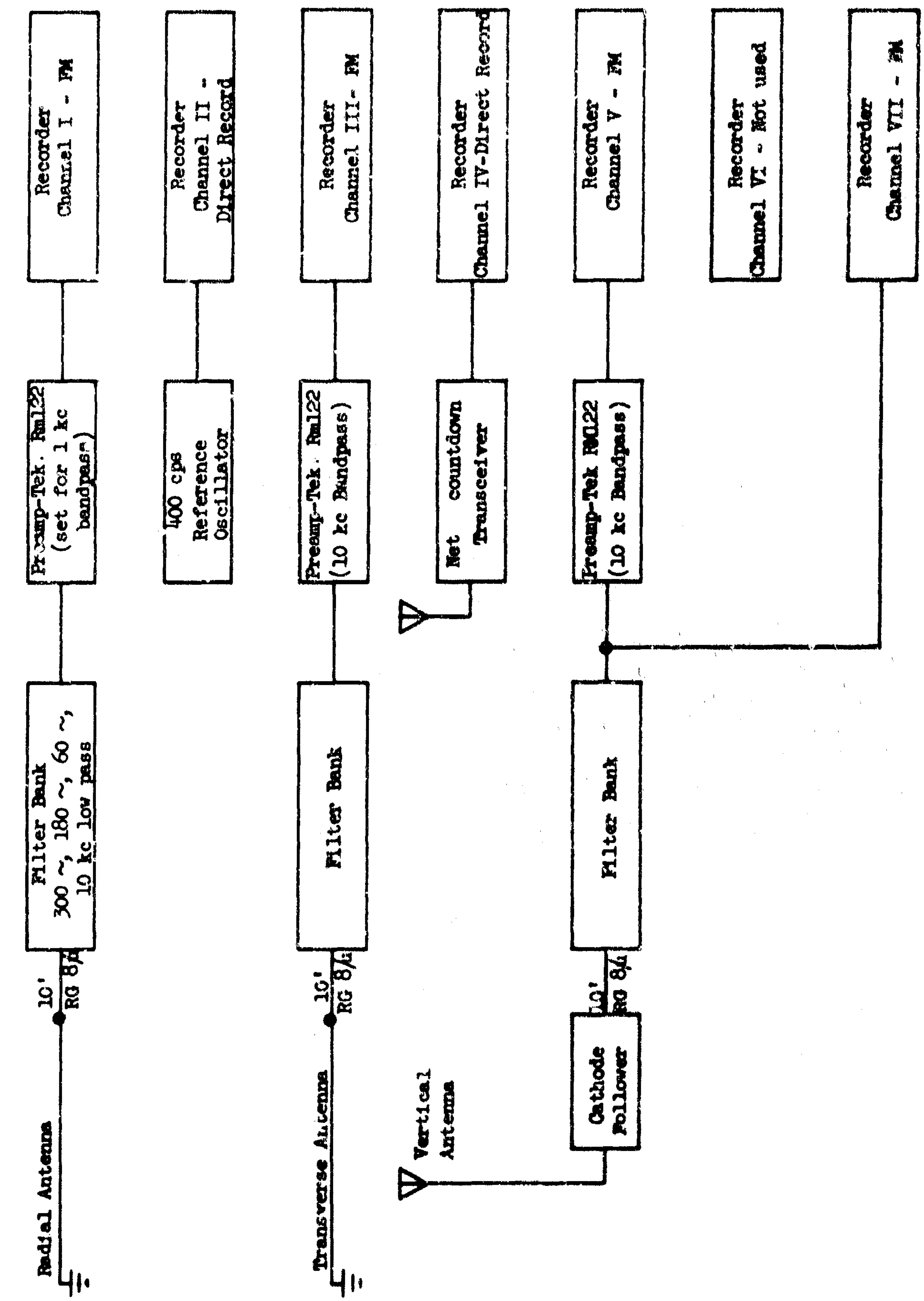


FIGURE 9. Instrumentation System at Stations I and II - HARDHAT TEST

The horizontal antennas were terminated to ground at the far ends by use of cadmium electrodes immersed in a cadmium chloride solution. The cadmium chloride solution was contained in a porous crucible that ensured constant contact with the earth. These crucibles were buried in the ground, at a depth where moist earth was encountered. In all cases this was a depth of from one to one and a half feet (see Figure 10).

At both stations the 12.5 foot vertical antennas were located at the junctions of the radial and transverse antennas. The output of each vertical antenna was fed directly into a cathode follower located at the base of the antenna. The output of the cathode follower, and the outputs of the radial and transverse antennas, were each connected to the input of a filter bank through a switch and patching panel. The use of the patching panel permitted convenient monitoring of the signals directly off the antennas, the signal inputs to the recorder, and off-the-tape monitoring of all channels. The channel assignments, band pass, and dynamic range for both stations were as follows:

Channel I	- Radial antenna, 40 db dynamic range (.0002 - .02 v input from antenna), .2 cps to 1 kc
Channel II	- 400 cps reference
Channel III	- Transverse Antenna, .0005 - .05 input, 40 db dynamic range, .2 cps to 7 kc
Channel IV	- Voice and countdown from the transceiver.
Channel V	- Vertical antenna, .0002 - .02 input, 40 db dynamic range, 20 cps to 7 kc
Channel VI	- Not used
Channel VII	- Vertical antenna direct; no amplification, .05 - 5 V input, 40 db dynamic range, 20 cps to 7 kc.

FIGURE 10. Photograph of Pyrex Gouch-Crucible and Tile Container

Channel band pass curves were very similar to the one shown in Figure 6, with 40 to 60 db of rejection at 60, 180, and 300 cps.

One exception to the above arrangement was made at Station I, where an additional 60 cps filter was used in the radial antenna channel to filter out a large 60 cycle interference at that location. This increased the 60 cps rejection from 40 to 60 db.

The average background noise at both stations during the test interval was 150 to 200 µv out of the filters for the horizontal antennas and 300 to 350 µv for the vertical antennas. This noise level resulted in a detectable signal sensitivity of 1-2 µv/meter for the horizontal antennas and about 200 µv/meter sensitivity for the vertical antennas.

Data for plotting frequency response curves for each signal channel was recorded on tape and in the station log book the day preceding the event. Dynamic range and calibration voltages were recorded two hours before the event.

The recorders were started at T-5 minutes and allowed to run until approximately T + 10 minutes in order to obtain a record of the background noise characteristics during the test period as well as to record any actual signals from the explosion.

Figure 11 is a photograph of the Space-General trailer on site at Station I and Figure 12 is a view of the interior of the trailer showing the equipment in the process of being set up.

FIGURE 11. Instrumentation Trailer at Site I - HARDHAT.

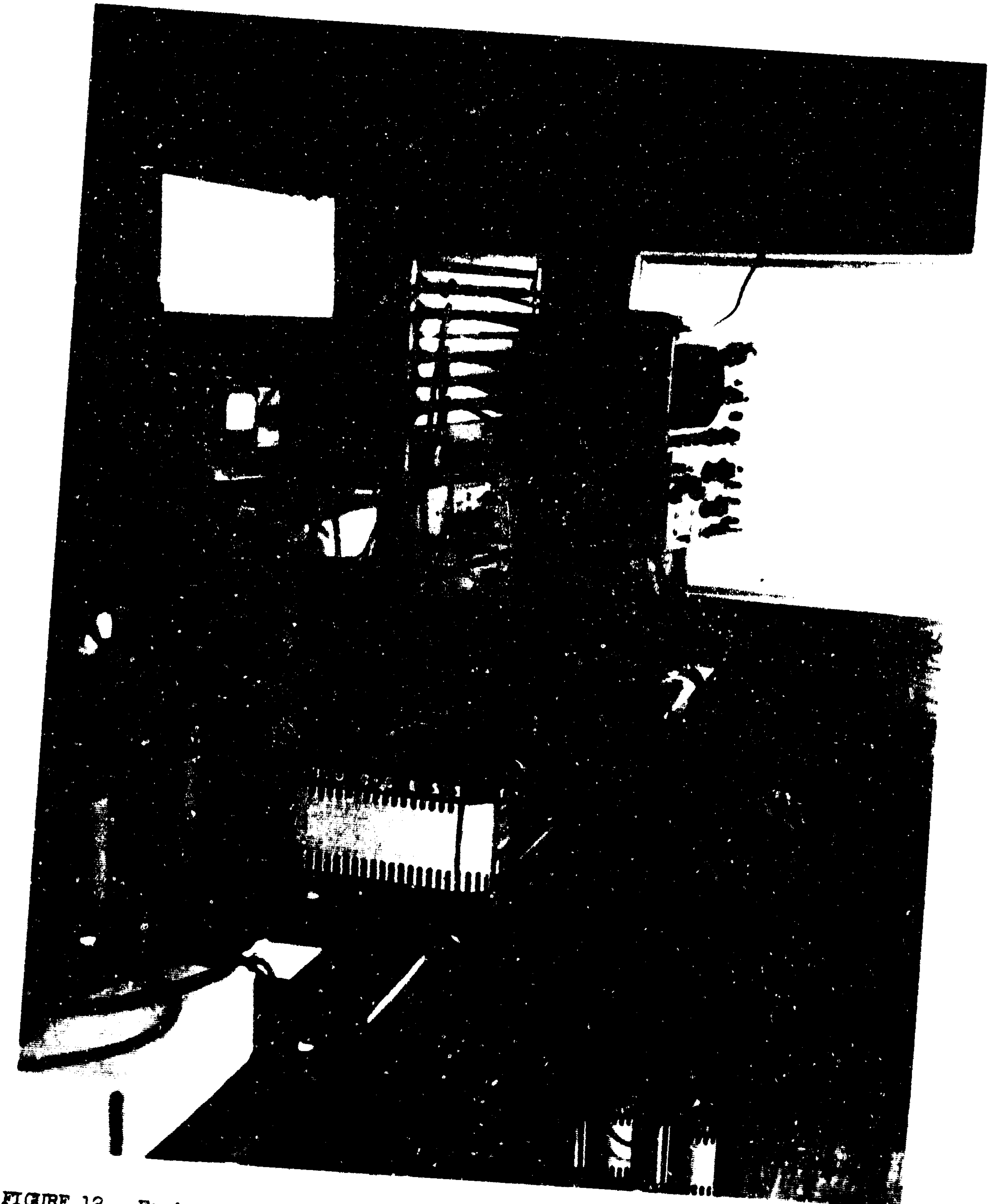


FIGURE 12. Equipment Set-Up in Space-General Corporation Instrumentation Trailer

5 0 EXPERIMENTAL RESULTS

5.1 PLASMA PROBE EXPERIMENT

The venting of GNOME resulted in radiation-fogged film and complete loss of data for this experiment.

5.2 ELECTRIC FIELD MEASUREMENTS

The electric field strength records from the GNOME test are presented in Figures 13 through 17 and the HARDHAT records are presented in Figures 18 through 20. From the standpoint of detection of underground shots, the most significant aspect of these records is that no signal which can be identified as originating from the explosion was received above background noise at any station other than the close-in site at the GNOME test.

Station I for the GNOME test was located 1180 ft from ground zero in a direction South 35° 30' West. Maximum signal strengths recorded at this station were of the order of 30 mv/meter on the radial antenna, 10 mv/meter on the transverse antenna, and 100 mv/meter on the vertical antenna. If it is assumed that the field is generated primarily by a magnetic dipole mechanism, as discussed in Section 2.0, then the electric field should fall off as the inverse square of the distance from the explosion and the field strength at a distance of 4.5 miles (station II) would be of the order of 100 μv/meter. A signal strength of this magnitude would have been detected above background noise. If the field was generated primarily by an electric dipole source, however, electric field strength would fall off as the inverse distance cubed and the signal would not be seen above noise at Station II.

The low frequency oscillation following the initial pulse,

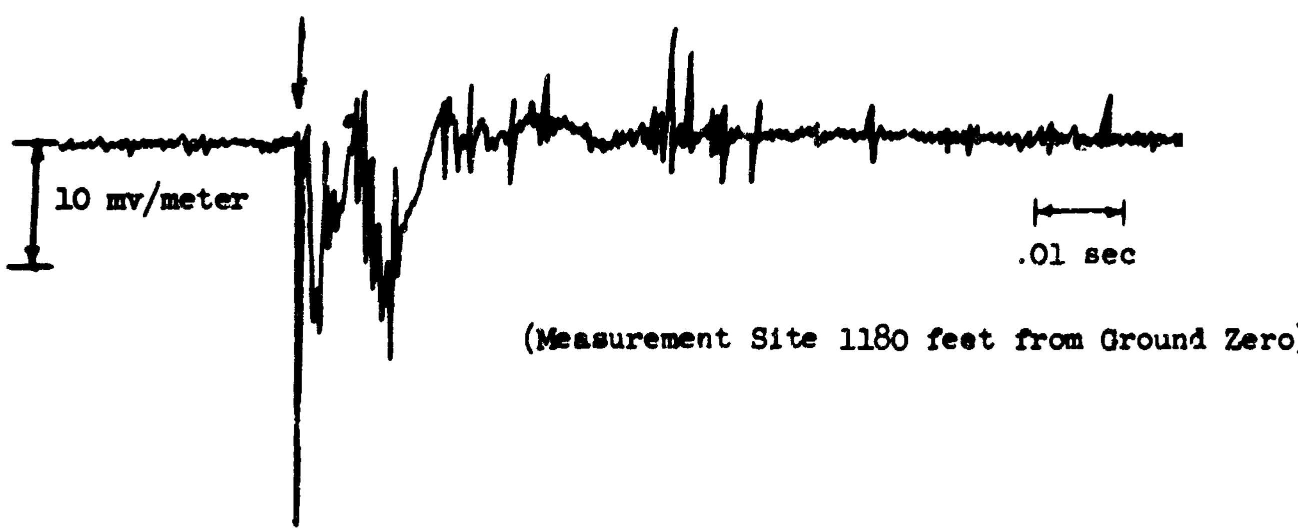
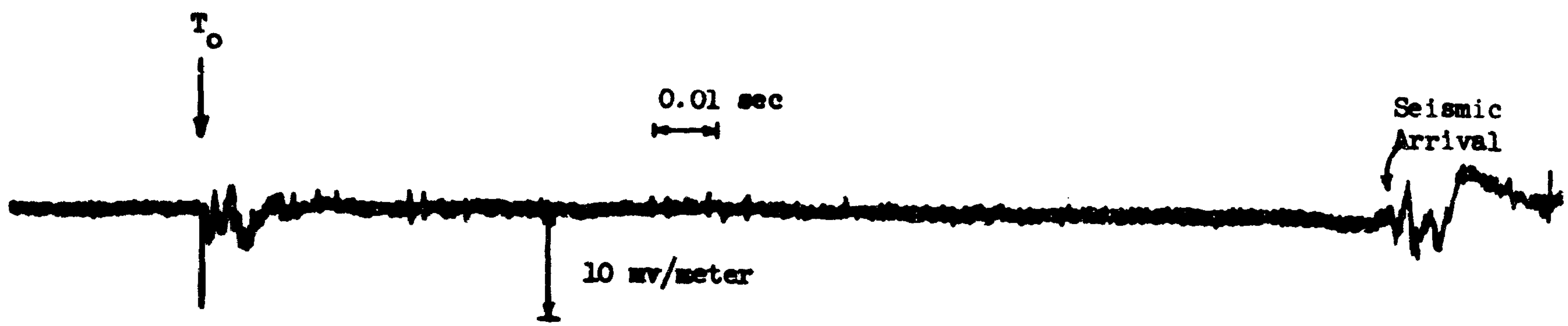


FIGURE 13. Radial Component of the Horizontal Electric Field from GNOME Test - STATION I.



(Measurement Site 1180 feet from Ground Zero)

FIGURE 14. Transverse Component of the Horizontal Electric Field from GNOME Test - STATION I.

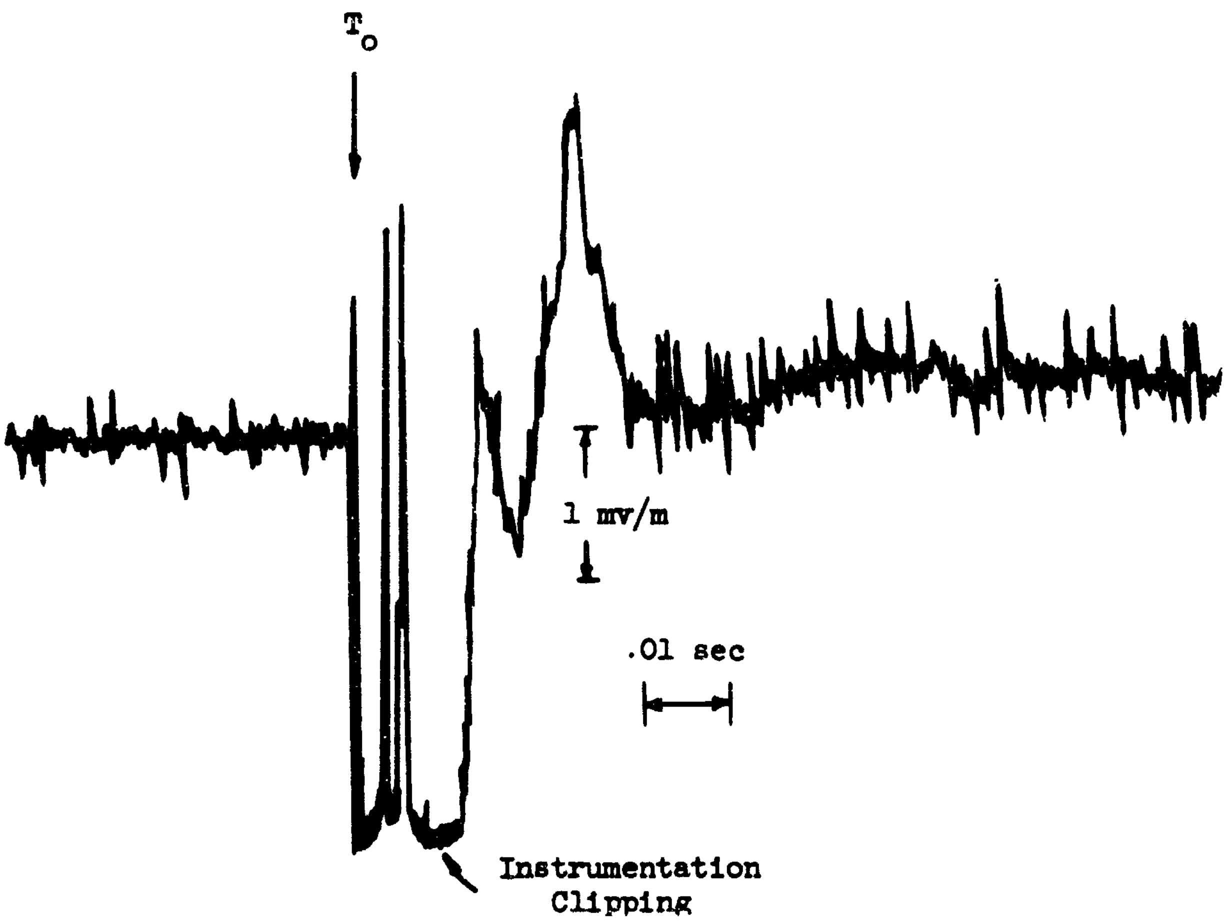


FIGURE 15. Transverse Component (Amplified) of the Horizontal Electric Field from GNOME - STATION I.

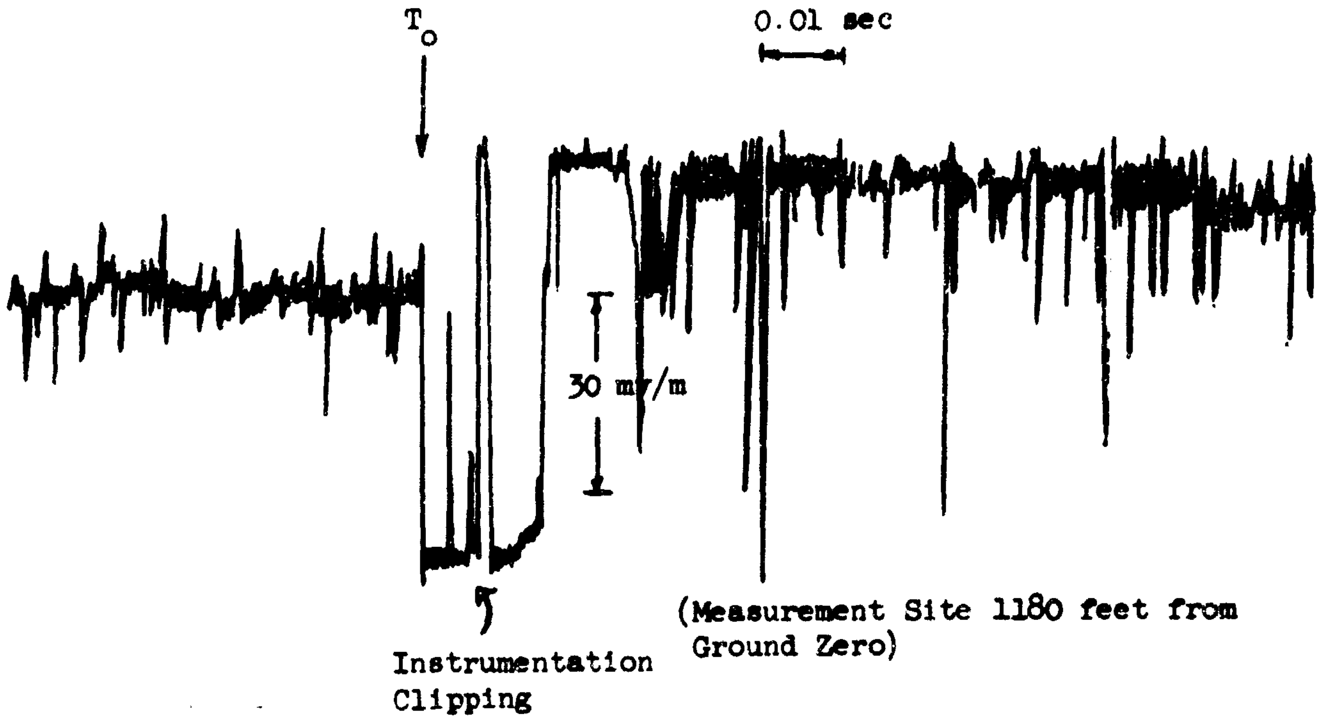


FIGURE 16. Vertical Component of the Electric Field from GNOME Test - STATION I.

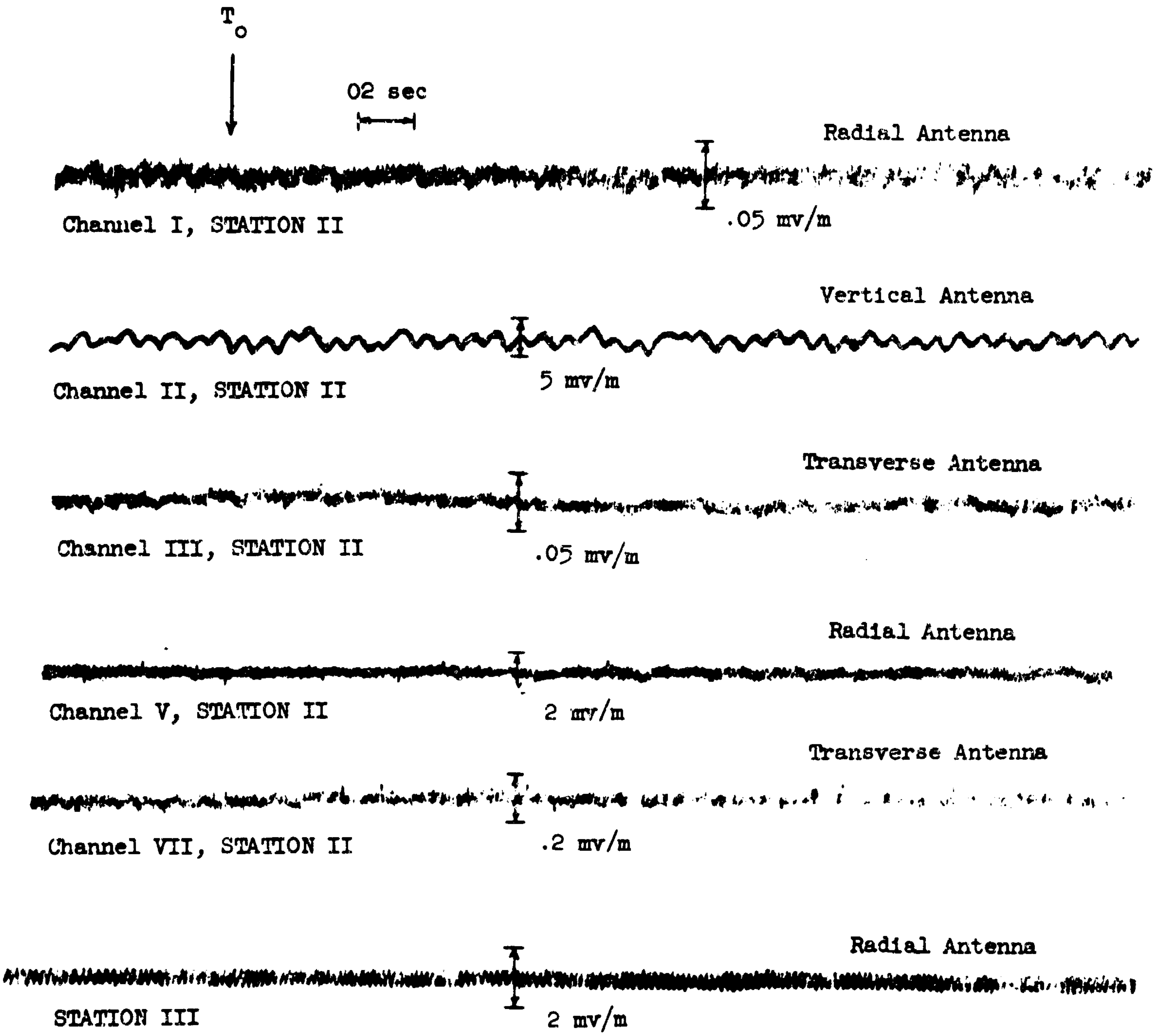


FIGURE 17. Field Strength Records from Stations II and III - GNOME .

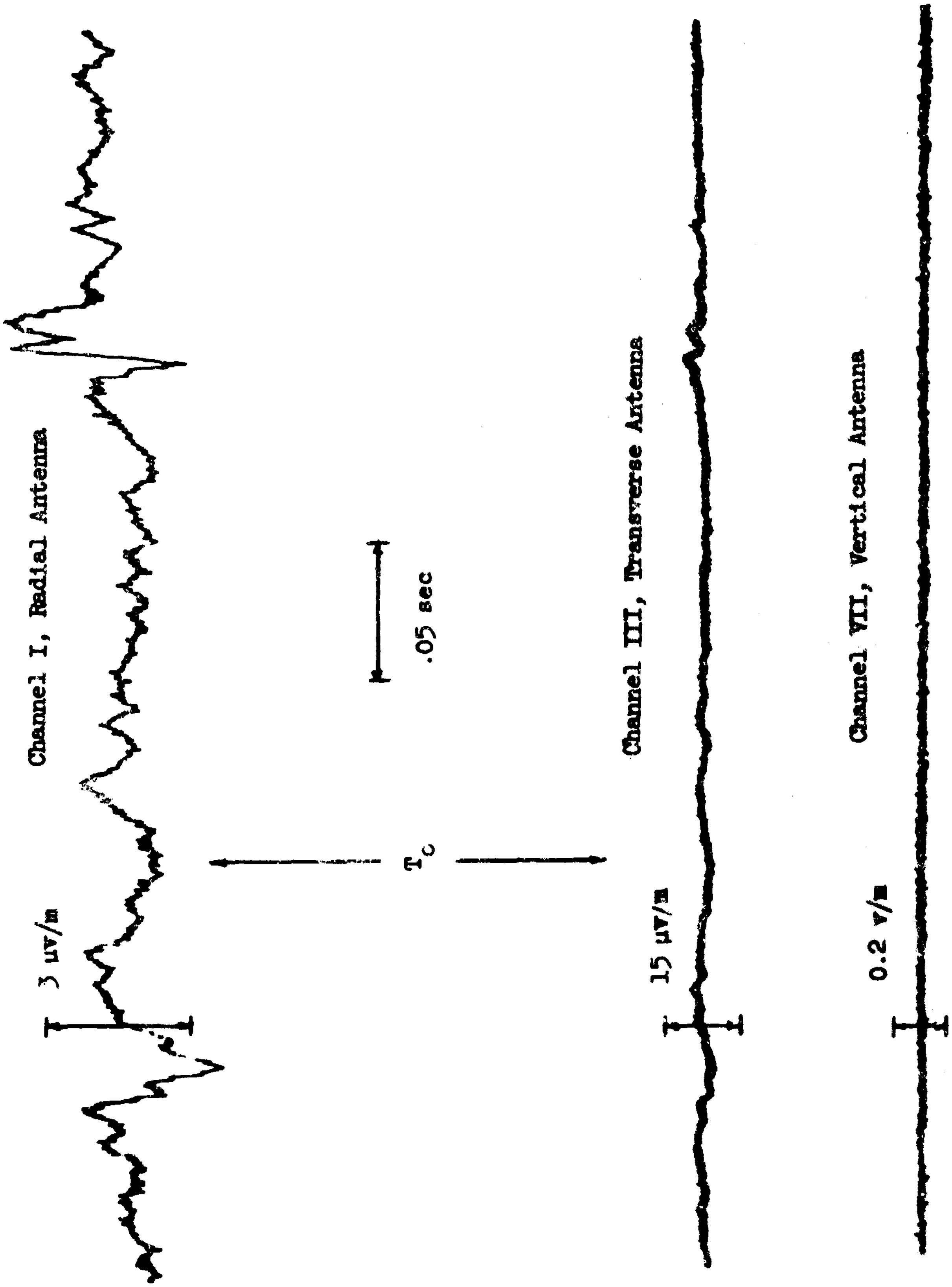


FIGURE 18. Electromagnetic Field Records at STATION II, HARDHAT.

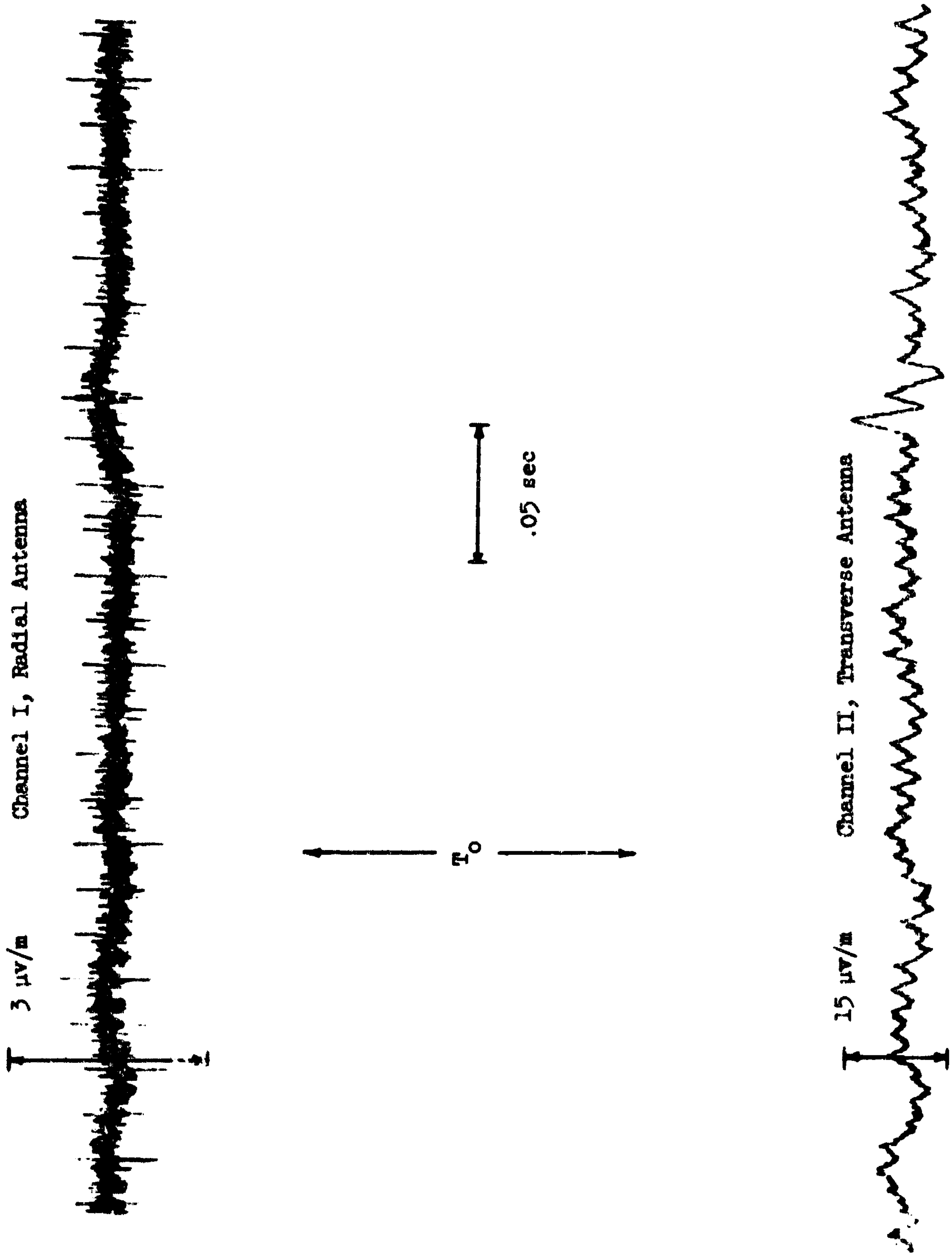


FIGURE 19. Horizontal Components of Electric Field at HARDHAT, STATION I

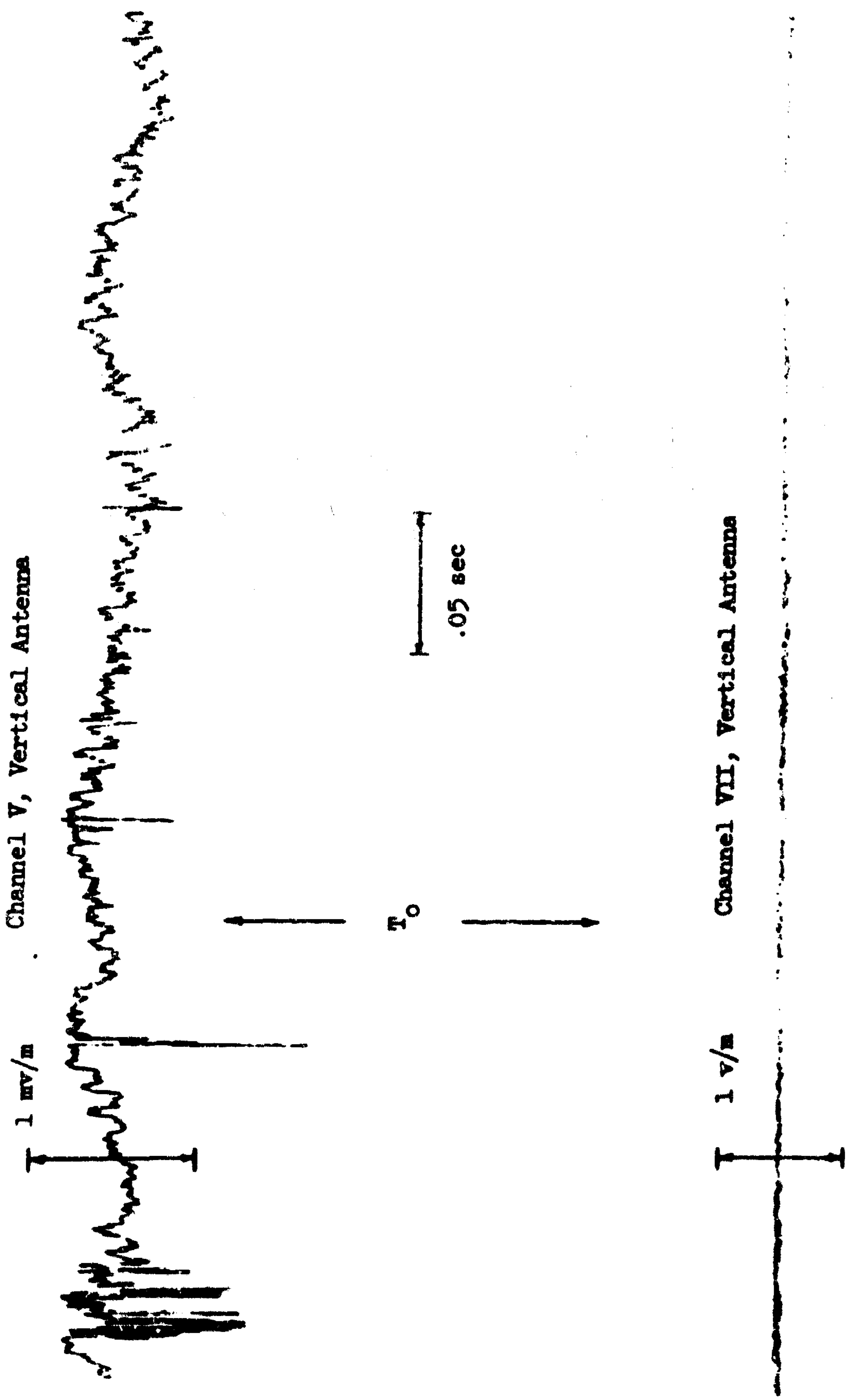


FIGURE 20. Vertical Electric Field at HARDHAT, STATION I.

which is seen to appear on all the GNOME Station I records, is caused by filter ringing in the data system and is not an actual characteristic of the signal from the blast. This is illustrated by Figure 21 which shows the response of the data system to a 3 millisecond pulse. The similarity between the filter ringing in Figure 21 and the low frequency oscillation in, for example, Figure 14 is immediately apparent. The signal from the blast actually consisted of an initial pulse at time t = o, of the order of 1-3 μsec pulse width, followed by a large number of secondary smaller pulses. Signal pulses were received as late as 0.1 seconds after T_o.

The signals received at Station I during the GNOME test were two orders of magnitude larger than predicted by the magnetic dipole horseback analysis discussed in Section 2.0. Furthermore, the radial dependence of the field appears to correspond more to an electric dipole source than to a magnetic dipole. It should be recognized, however, that signals from the GNOME shot may not be typical of underground explosions. The large neutron pipe which extended down the access tunnel to the device room, and which actually had one end in contact with the bomb plasma, almost certainly acted as a radiating antenna and even possibly was the principle source contributing to the electromagnetic field. From previous experiments conducted with metallic pipes which were in contact with the plasma during underground shots, it is known that very large charging currents flow down the pipe and the pipe potential reaches possibly thousands of volts.[5]

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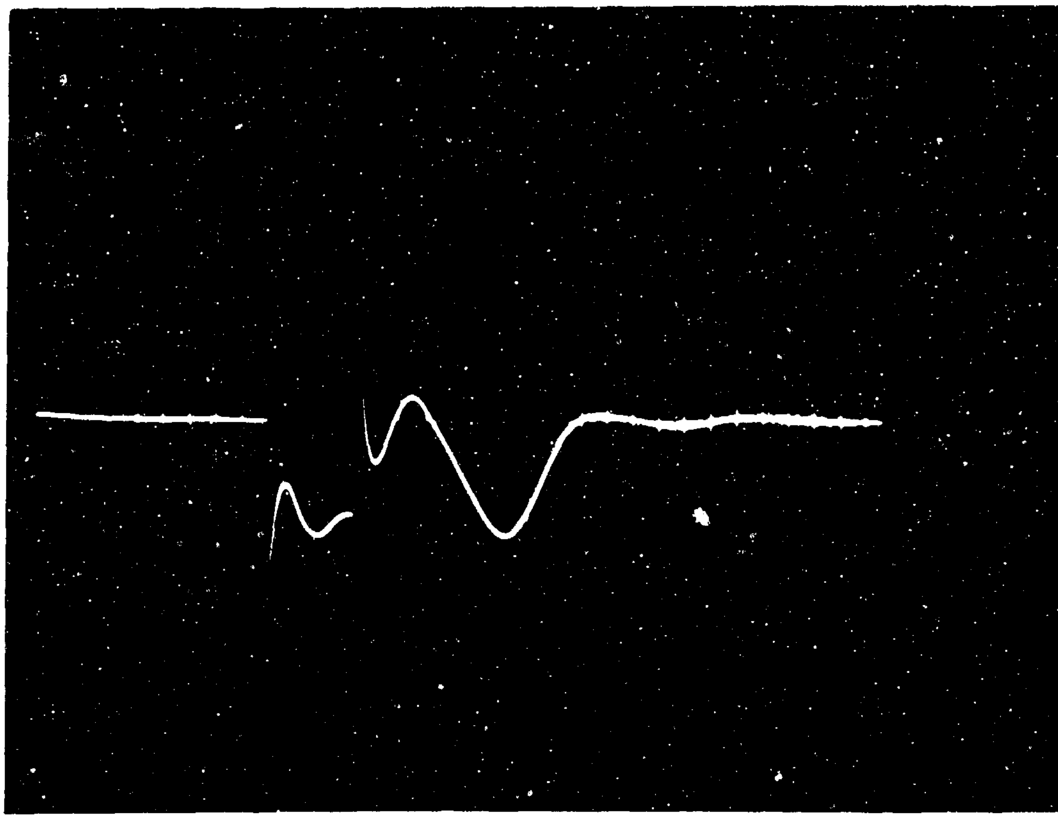
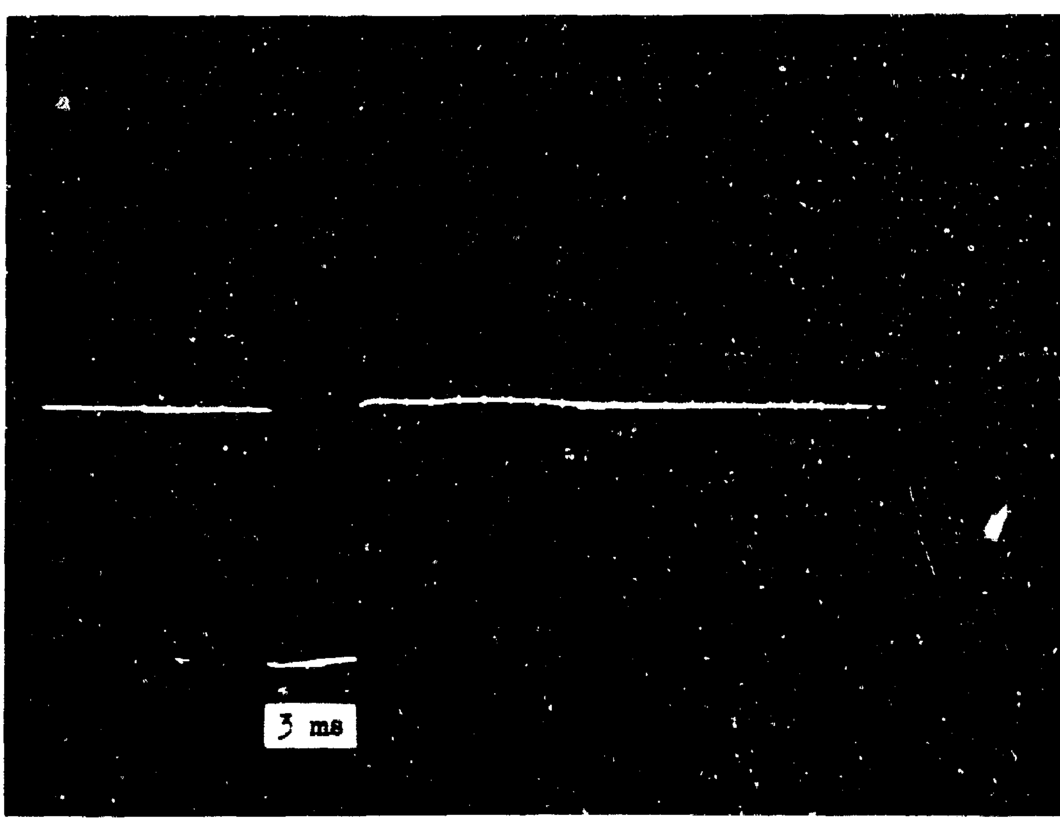
(5) Private communication with Dr. L. F. Wouters, Lawrence Radiation Laboratory, Livermore, California



a. Data Channel Response to 3 millisecond Square Pulse



b. Square Pulse Which Produced Data Channel Response Shown Above

FIGURE 21. Curves Illustrating Filter Ringing in Data System.

It was the potential on this pipe which the "plasma probe" experiment was designed to measure. The loss of data due to radioactive fogging of the film in this experiment is highly regretable, since the film records would have provided information to evaluate the electromagnetic source properties of the pipe as well as the properties of the plasma. In addition to the neutron pipe, there were a number of metallic structures both above ground and underground near the device room which may have acted as secondary radiators.

6.0 CONCLUSIONS

The data obtained during the GNOME and HARDHAT tests show that the electromagnetic signals generated by low-yield close-coupled underground nuclear explosions are small in magnitude and cannot be detected above background noise at distances more than a few kilometers from ground zero. This experimental conclusion is in complete agreement with the results of theoretical studies conducted at the Space-General Corporation.

No conclusions can be drawn in regard to the magnitude of the electromagnetic signals generated by de-coupled shots which take place in large cavities. Theoretical work presently in progress at Space-General[6] will result in theoretical predictions of the field strengths to be expected from de-coupled explosions. Final conclusions concerning the feasibility of electromagnetic detection of de-coupled underground nuclear detonations can be made only after the electromagnetic signals from such explosions have actually been measured.

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(6) "Theoretical and Model Studies for the Production of Electromagnetic Signals from Underground Nuclear Detonations", AF30(602)-2500.